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Dynamically Optimizing End-to-End Latency for Time-Triggered Networks

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一. Background

二. Motivation

三. Best TT Protocol

四. Evaluation

五. Conclusion and Future Work

Background

□ Industrial Ethernet



Network is an important carrier of data communication, and thus, is essential infrastructure.



Field bus

low Bandwidth



**High Bandwidth
realtime**



**High Bandwidth
no realtime**

Background

❑ Characteristics of Industrial Ethernet

- ❖ Integrated Network

- ❖ For Industry

- Realtime control (**Customizable end-to-end latency**)
- Since different control instructions may have different latency requirements

- ❖ For Ethernet Users

- High bandwidth with QoS such as priority, traffic shaper, etc.

Note: QoS based realtime is not the realtime for Industry control because the former provides the upper bound of end-to-end latency that is nearly no customizability.

Background

□ Time-triggered (TT) Networks

❖ TTEthernet

- For aerospace
- Provided by the Society of Automotive Engineers Group

❖ Time-sensitive Networking (TSN)

- To standardize Industrial Ethernet
- Provided by the 802.1Q Group

❖ The common characteristics

- Using time-triggered transmission for industrial control
- So-called Time-triggered Networks

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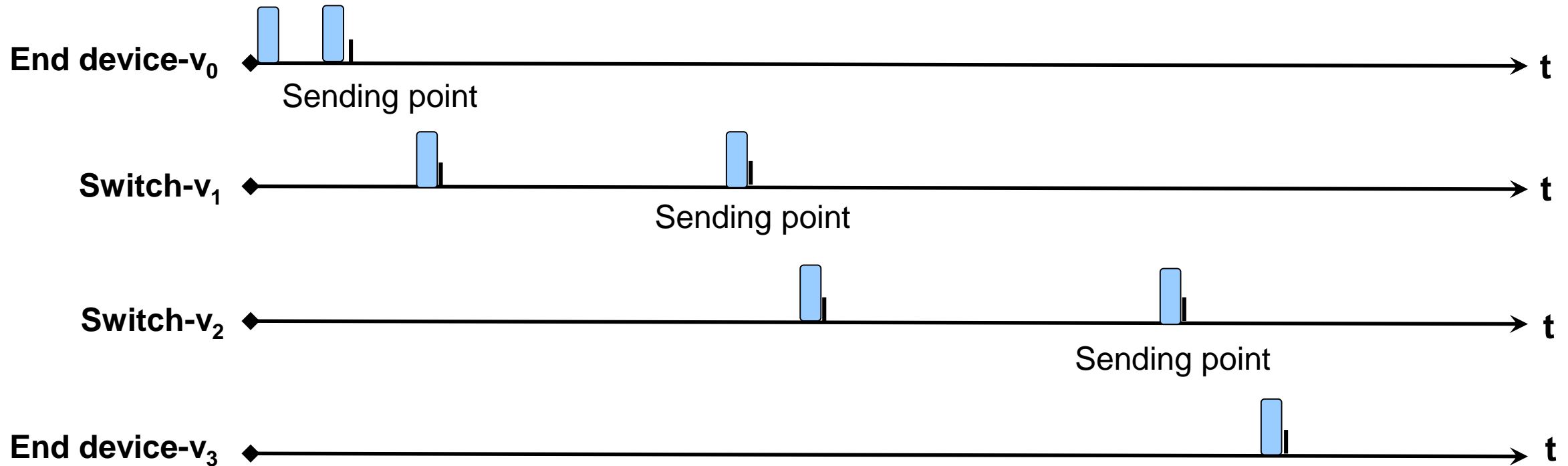
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Motivation

□ Time-triggered Transmission

❖ For example, a frame from End v_0 to End v_3



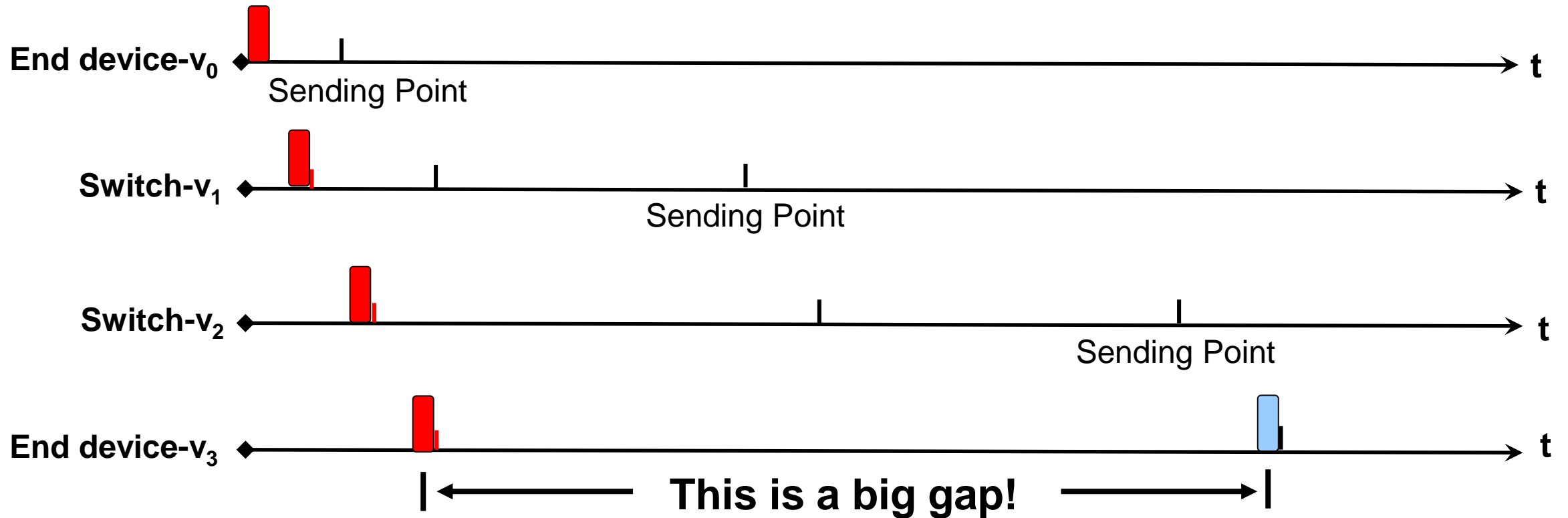
❖ To customize end-to-end latency

➤ By scheduling these sending points

Motivation

❑ Best-effort Transmission

❖ The frame is transmitted from End v_0 to End v_3 again.



Motivation

□ The Problem

❖ When transmitting a frame

- How to make TT transmission as upper bound
- and the same performance (latency) as BE transmission ?



□ The Solution

- ❖ The **BE** Assisted **TT** Communication **Protocol**
- ❖ So-called **BEST TT Protocol**

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Best TT Protocol

□ TT Transmission VS BE Transmission

❖ TT transmission

- Customizing end-to-end latency by scheduling sending points
- Order-preserving due to scheduled sending points

➤ BE transmission

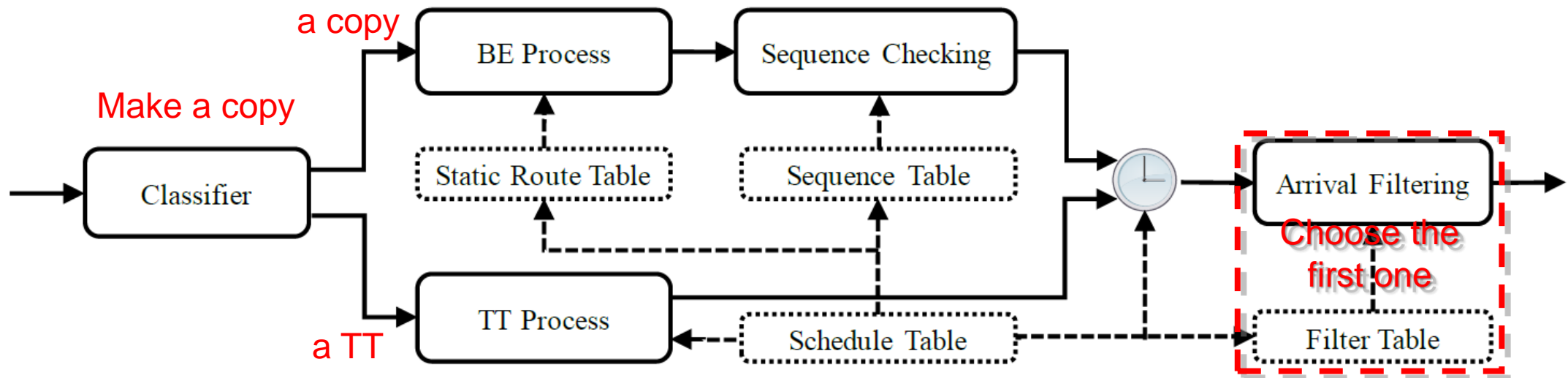
- Queueing leads to a longer latency than that of TT frames
- Even dropping frames leads to the unreachable frames
- Rerouting leads to out of order
- Congestion may be partial
 - ✓ A switch has frame loss due to congestion but remaining path is free congestion

How can we conquer the uncertainty of BE transmission to optimize and maintain the properties of TT transmission?

Best TT Protocol

❑ Basic Idea

- ❖ To make a copy for each TT frame
- ❖ To deliver the copy with best effort transmission
- ❖ Either a TT frame or its copy
 - the first arriving at the destination device as the final delivery
 - and ignoring the other one.



Best TT Protocol

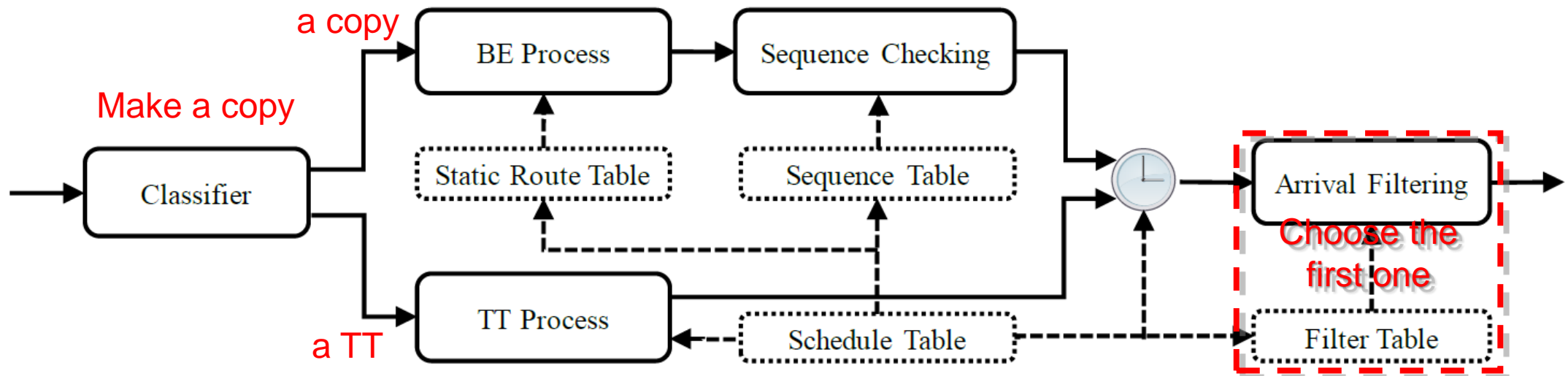
❑ To conquer the uncertainty of BE transmission

❖ For queueing even drop frames

- Either a TT frame or its copy, the first arriving at the destination device as the final delivery and ignoring the other one.

❖ For partial congestion

- Each switch attempts to make a copy



Best TT Protocol

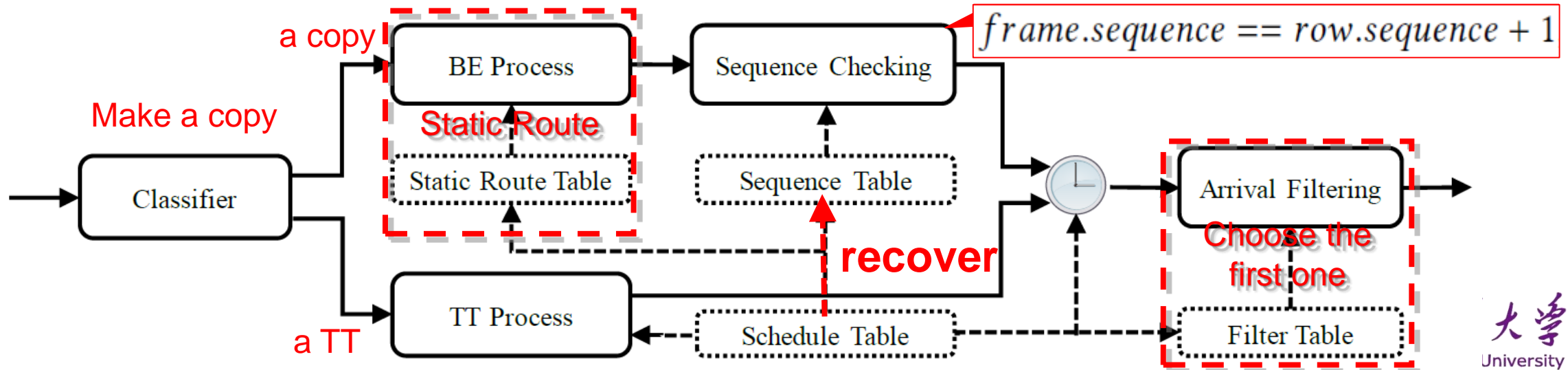
❑ To conquer the uncertainty of BE transmission

❖ For rerouting

- Static routes with the same paths as TT frames

❖ For surpassing

- A sequence-based order-preserving strategy is proposed to drop such surpassing copies and recover the right sequence



Best TT Protocol

❑ Four properties of Best TT Protocol

❖ Preserving Order

- the order of different frames sent by the start device is kept in the end devices

❖ Self-recovery

- if a copy is dropped, the transmission of the next copy will not be affected.

❖ Dynamic Optimization

- The variable latency optimization due to the dynamic network load

❖ Cost Efficiency

- For each TT frame, no more than one copy is transmitted in the whole network.

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Evaluation

❑ Experiment Setup

❖ Scenario One (**Latency Optimization**)

- To demonstrate copies are always running men in spite of the disturbance of other data
- So, to assign copies higher priority than other BE data

❖ Scenario Two (**Upper Bounds**)

- To demonstrate latency of TT frames is the upper bounds
- So, to assign copies the same priority as other BE data and adjust the bandwidth of other BE data to let copies queueing even loss

Evaluation

❑ Experiment Setup

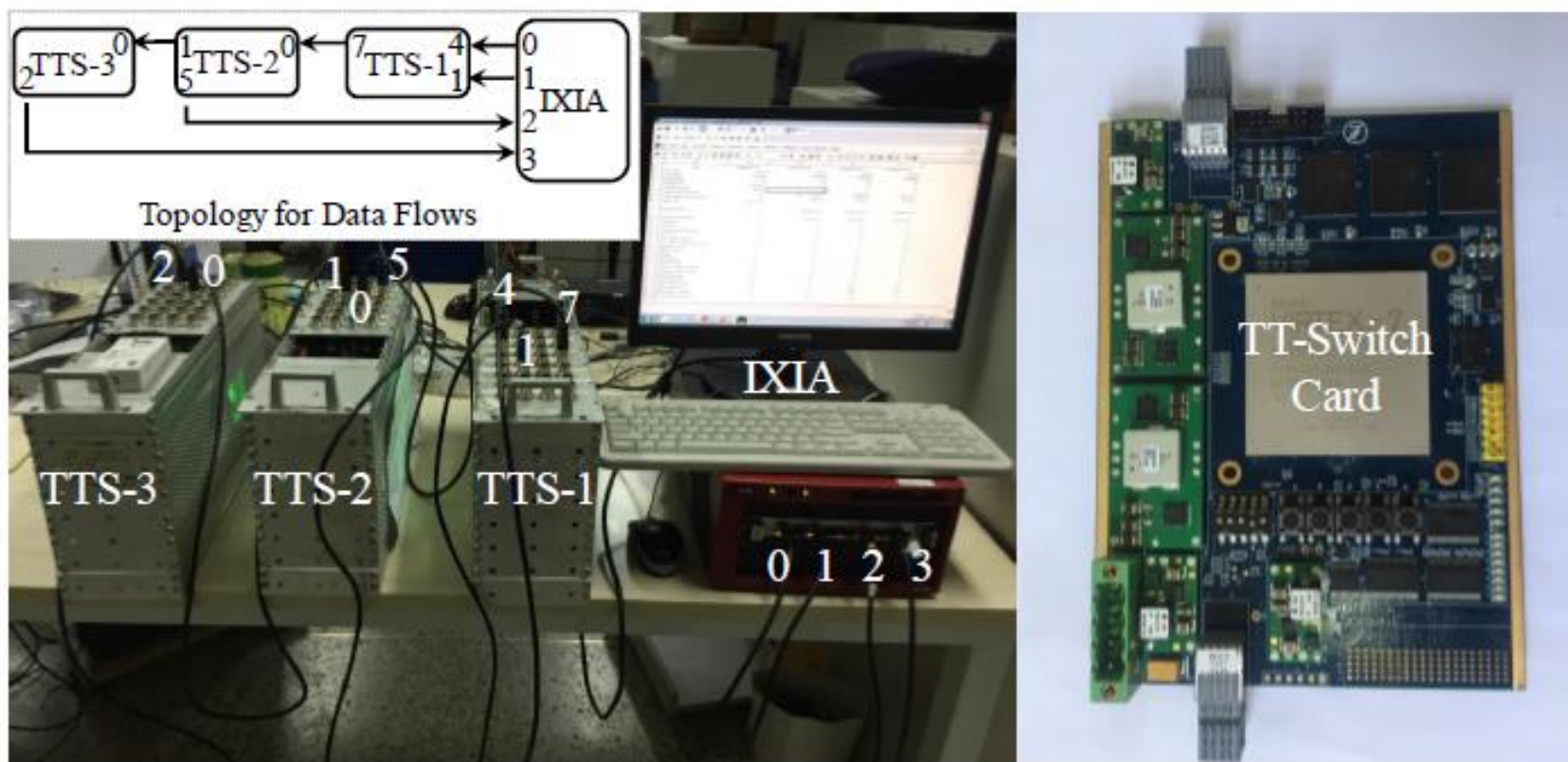
❖ Scenario Three (**Self-recovery**)

- To demonstrate the self-recovery when the congestion has gone
- So, to assign copies the same priority as other BE data
- to adjust the bandwidth of other BE data to let copies queueing even loss and let queueing even loss only happen in partial switches.

Evaluation

❑ Experiment Setup

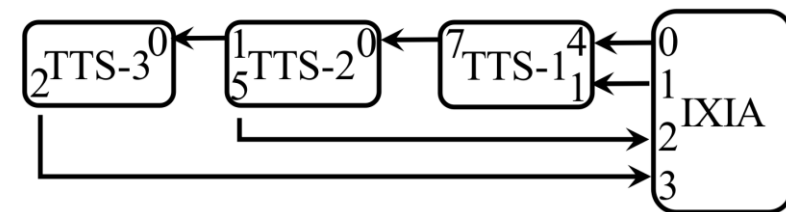
❖ The experiment platform



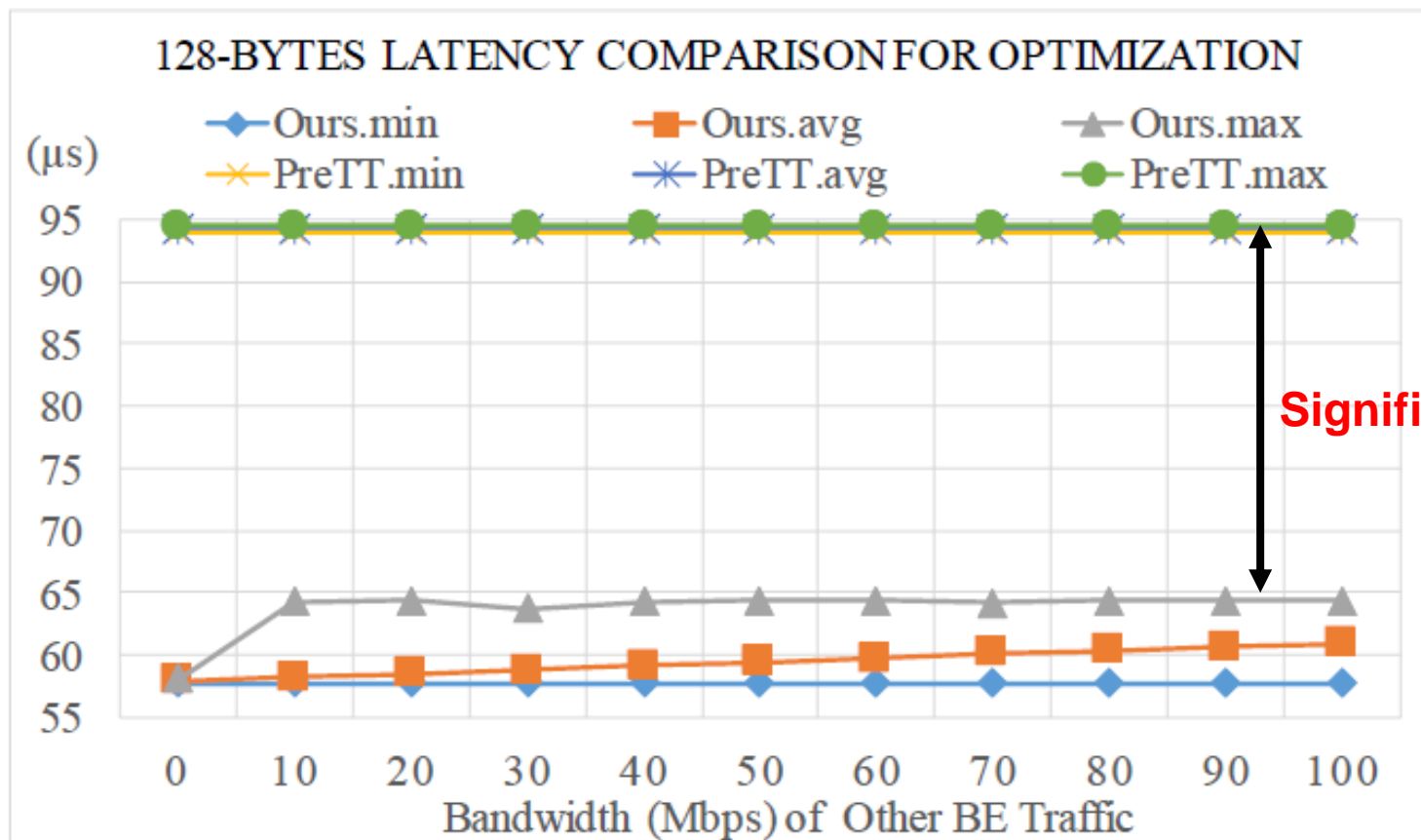
Evaluation

Scenario One (Latency Optimization)

❖ Significant improvement for latency



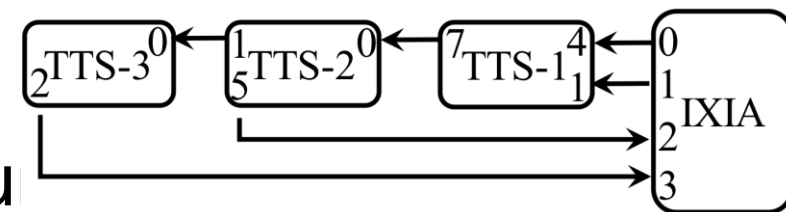
Topology for Data Flows



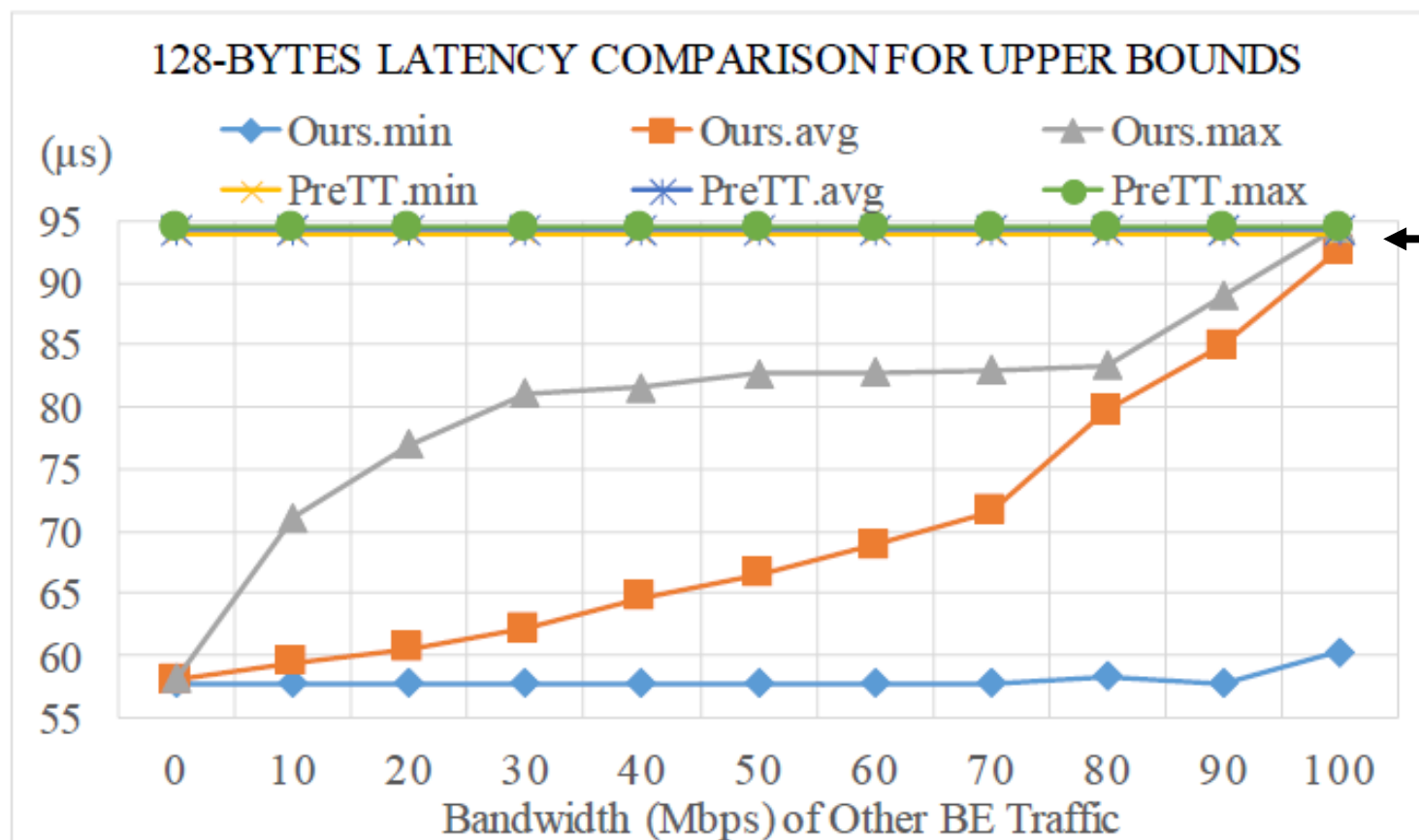
Evaluation

Scenario Two (Upper Bounds)

❖ The latency of TT frames are the upper bound



Topology for Data Flows

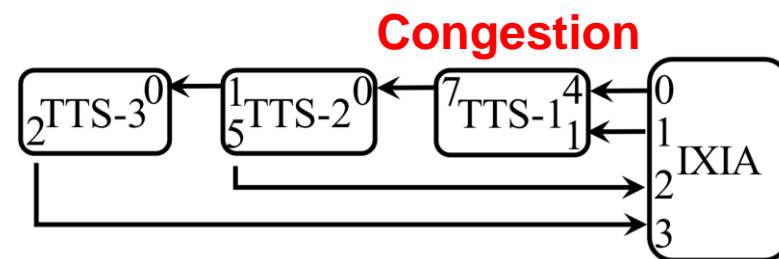
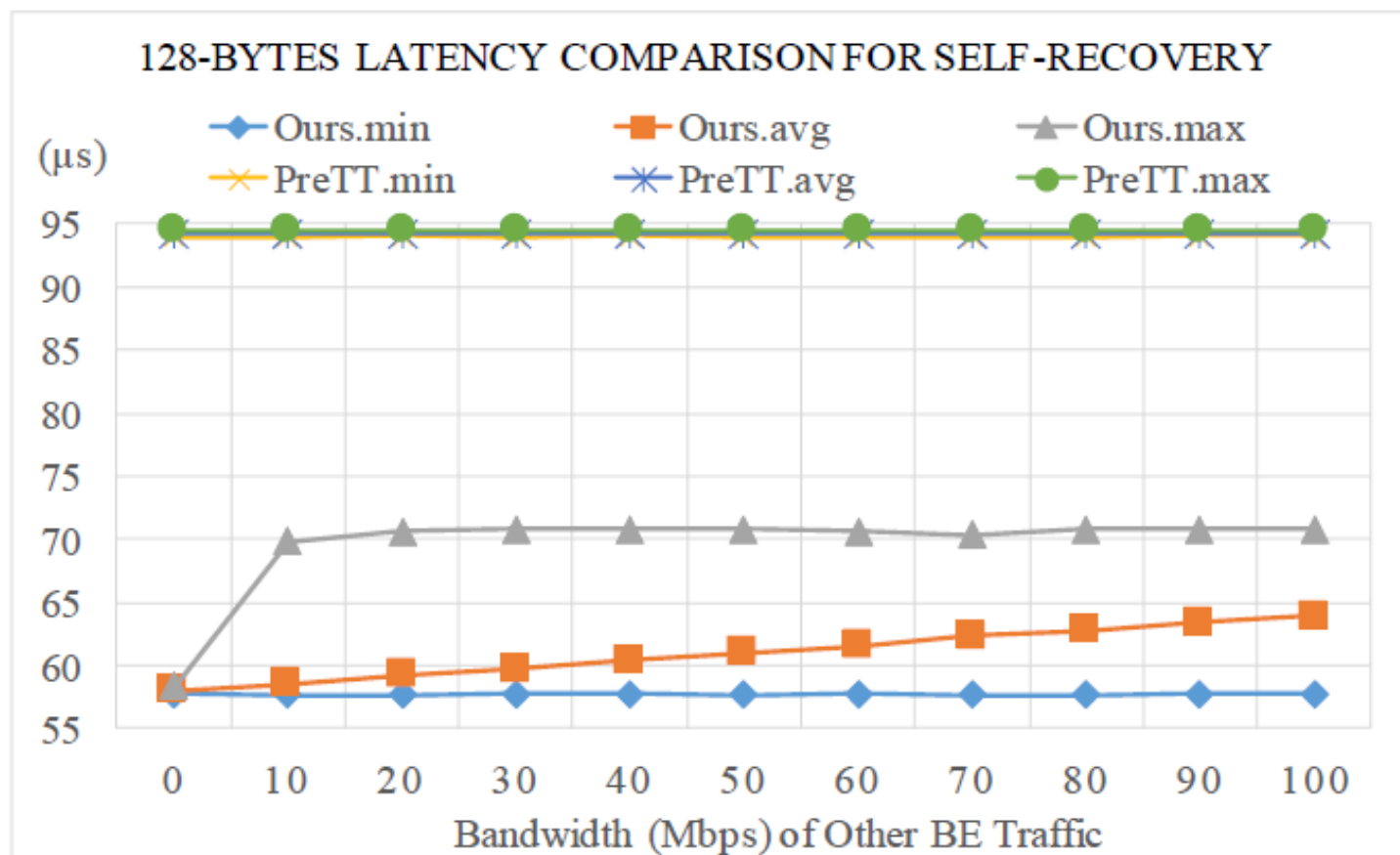


Upper bound

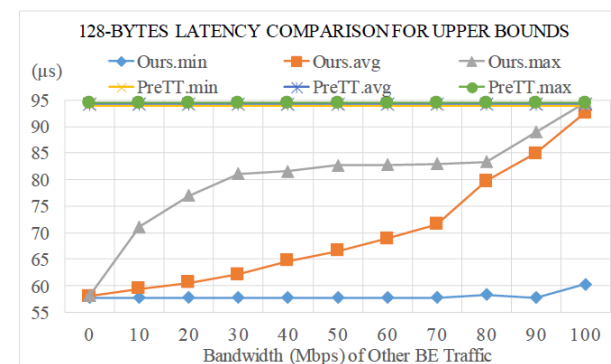
Evaluation

Scenario Three (Self-Recovery)

Partial optimization(TTS-2,3)



Topology for Data Flows



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Conclusion and Future Work

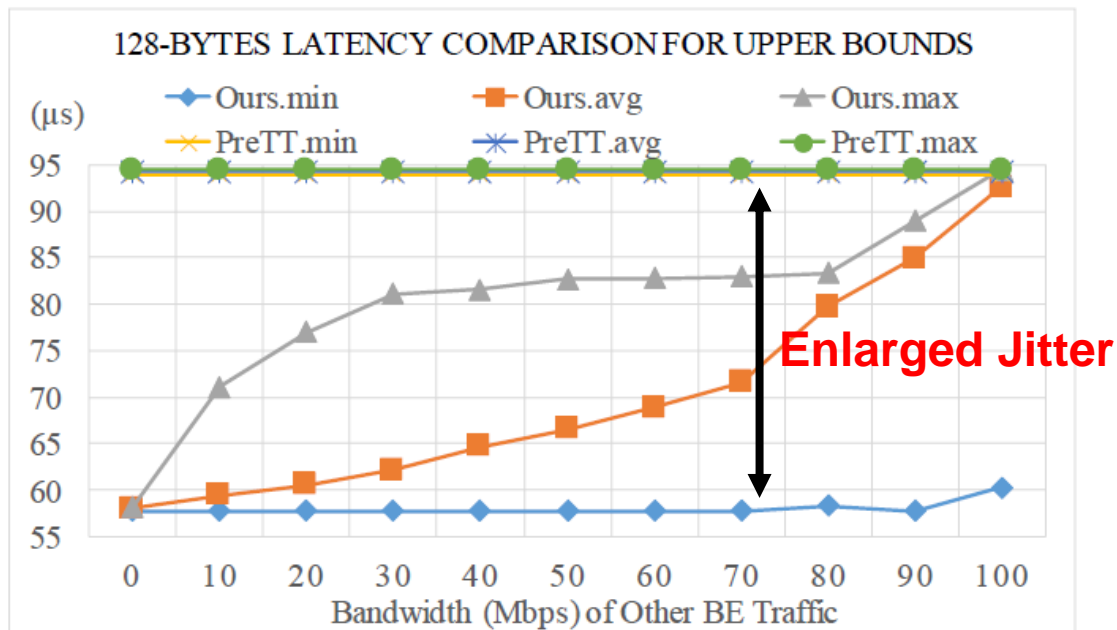
□ Conclusions

- ❖ We proposed the BEST TT Protocol
 - Tackling the uncertainty of BE transmission
 - Dynamically optimizing the latency of TT transmission
- ❖ We implemented the protocol in our TT switches
- ❖ We demonstrated the protocol
 - By designing three scenarios for latency optimization, upper bounds and self-recovery

Conclusion and Future Work

□ Future Work

- ❖ Optimizing the latency but enlarging the jitter of the latency



- ❖ The next work is to extend the protocol for configurable jitters

THANK YOU!
Q & A